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FIRE TUBE WOOD BOILER FOR DOMESTIC USE

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

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Fire tube wood boiler for domestic use /
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FIRE TUBE WOOD BOILER FOR DOMESTIC USE

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July, 1978

Prepared for

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32 South Ewing, Helena, Montana 59620
Renewable Energy and Conservation Program
Grant Agreement Number 374-761

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I. Objective

To design, construct and test a wood-fired boiler used in conjunction with a heat storage unit to heat a single-family dwelling.

II. Project Implementation

A. Project Planning and Equipment Acquisition

SYSTEM DESIGN

When consideration is given to the design of a heating system for a domestic building, the first unknown that must be found is the total heat loss in the building. Using this figure, the size of the heat storage unit and the size of the boiler can then be found.

BUILDING HEAT LOSS

The location and types of building materials that are subject to heat loss in the house under study appear in Table 1, p. 2a. The data in this table summarize the numbers of square feet of each building system (walls, ceiling, etc.) that have a similar coefficient of heat loss. These figures were then used in Table 2 to find the total heat loss through each building system. The total number of square feet was multiplied by the coefficient of heat loss for that system. The U factor for each building system was found by adding the U factors for all the components used in each building system. For example, the U factor for the ceiling is an addition of the sheetrock used (R=.45) and the fiberglass insulation (R=3.70 per inch or 44.4 for 12 inches)

TABLE 1

SQUARE FOOTAGE OF BUILDING SYSTEMS IN THE HOUSE

	Ceiling (sq. ft.)	Floor (sq. ft.)	Walls(ext.) (sq. ft.)	Doors(ext.) (sq. ft.)	Windows (sq.ft.)
Family Room	204	204	144	0	42
Kitchen	120	120	96	0	17
Study	108	108	200	0	16
Utility Room	150	150	208	20	17
Living Room	325	325	480	0	90
Master Bedroom	180	180	256	0	46
Bedroom #2	115	115	96	0	20
Bedroom #3	130	130	48	0	20
Hall	39	39	0	0	0
Master Bathroom	120	120	144	0	8
Bathroom	62	62	48	0	8
Entry	129	129	48	20	9
TOTAL	1682	1682	221	40	293

for a total R value of 44.85. The R value symbolizes the resistance to heat flow and is the reciprocal of the U value (heat loss coefficient). As a result, 44.85 (R value for the ceilings) is divided into one, giving the U value for the ceiling building system. The product of the area and the heat loss coefficient is then multiplied by the design temperature difference to equal the heat loss per hour through each separate building system.

TABLE 2

TOTAL HEAT LOSS IN BTU PER HOUR BY TRANSMISSION AND INFILTRATION

Structure	Area or Volume (sq.ft. or cu. ft.)		U Factor	Design Temperature Difference (°F)	Heat Loss Per Hour (Btu)
ceilings	1682	sq.ft.	.022	90	3330.36
floors	1682	"	.168	10	2825.76
walls	1768	"	.040	90	6364.8
doors	40	"	.050	90	180.0
windows	293	"	.609	90	16059.33
infiltration	3364	cu.ft.	.018	90	5449.68
	TOTAL Heat Loss in Btu/hr.				34209.93

The design temperature difference in Table 2 is calculated by subtracting the low annual average for the locality of the study (-20°F) from a comfortable home interior temperature (70°F). This gives the design temperature difference for all building systems exposed to the outside. It should be noted that the design temperature difference for the floors is much lower because the basement is to be heated. The products of the area, U factor and design temperature difference are then totaled to find the total heat loss in the house used in the study.

The amount of air infiltration is found by finding the total volume of air in the house and using one-fourth of that figure (one-fourth of the air is displaced every hour). A new home may have one-half of the air displaced every hour. * However, due to the fact that the house used during the study has an uninterrupted plastic film as a vapor barrier, magnetically sealed steel doors and windows that were installed and insulated with care, a value of one-fourth of the volume being displaced every hour was used.

It should be noted that even though the window area was a small fraction of the total area exposed to heat loss, the heat loss through the windows is almost equal to that of the other areas combined (windows--16059.33 Btu per hour heat loss, combined other areas--18150.60 Btu per hour heat

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*Burgess H. Jennings, Heating and Air Conditioning (Scranton: International Textbook Co., 1956), p. 152.

loss, data from Table 2, p. 28). The windows used were Anderson thermopane windows and their heat loss could be greatly reduced through the use of additional storm windows.

HEAT STORAGE UNIT

Having found the total heat loss in the house (34209.93 Btu per hour), it is possible to calculate the size of the heat storage unit needed. Two factors are involved when determining the size of the heat storage unit. First it was determined that the heat storage unit should hold enough heat to keep the house at 70°F with an outside temperature of -20°F for at least 36 hours. Using a temperature difference of 100°F in the tank (100°F minimum for effective heating to a maximum of 200°F), it was then possible to calculate the size of the storage tank. The following formula was developed by the researcher for this purpose.

$$V = \frac{(H_{loss})\ (H_s)}{(\Delta t)(W)(S_n)}$$

where:

V = volume of heat storage medium

H_{loss} = heat loss per hour in house (34209.93 Btu/hr)

Δt = temperature difference in tank, maximum minus minimum (100°F)

W = weight in pounds of storage medium (water = 8.3 lbs/gal)

S_n = specific heat of storage medium (specific heat of water = 1.00)

so:

$$V = \frac{(34209.93)\ (36)}{(100)(8.3)(1)} = 1483.8 \text{ gal.}$$

Using this figure for the number of gallons in storage, a tank measuring four feet in diameter and sixteen feet in length was ordered. This tank was calculated to have a 1504.03 gallon capacity.

BOILER

The size of the fire box was of initial concern because it was thought that it should hold enough wood to heat the water in the storage unit 100°F. As a result, only one loading and firing would be necessary for a day and a half of heat for the house. The following formula was developed to find the size of the fire box.

$$V_{fb} = \frac{Btu_{load}}{(W)(H)(E)}$$

where:

V_{fb} = volume of the fire box in cubic feet
Btu_{load} = number of Btu's per load
W = weight of lodgepole per cubic foot (24 lbs/ft^3)
H = number of Btu's of heat in a pound of dry wood (8600 Btu/lb)
E = estimated efficiency of the boiler (.50)

In order to find the number of Btu's per load needed to heat the water in the storage unit 100 degrees, a simple calculation was used. The temperature difference ($100^\circ F$) is multiplied by the number of pounds of water in the tank (1500 gallons at 8.3 pounds per gallon = 12,450 pounds). Therefore $100^\circ F$ multiplied by 12,450 will equal 1,245,000 Btu's in storage. This figure was used in the formula as the number of Btu's per load.

Using the formula for the volume of the fire box, its dimensions were calculated:

$$V_{fb} = \frac{1,245,000}{(24)\ (8600)\ (.50)} = 12.0639 \text{ cubic feet}$$

Because sheet steel is obtainable in varying lengths and widths of four feet, it could be made four feet long with less waste. The final dimensions of the fire box were then calculated to be 27 inches high by 22 inches wide by 46 inches long, giving a total volume of 15.8 cubic feet. When split wood is stacked, there is actually only 80% actual wood in the total volume due to the air spaces. Eighty percent of 15.8 is 12.64 cubic feet of actual wood in the fire box. Burning this amount of wood should produce the necessary Btu's to raise the water in the heat storage unit 100 degrees.

After the size of the firebox was calculated, it was necessary to find the amount of heat absorption area needed to transfer the heat from the burning wood to the water for heat storage and distribution. The following formula was used for this calculation:

$$A = \frac{(H_p)\ \text{Btu/hr}}{K}$$

where:

A = surface area exposed to heat transfer in squ. ft.
K = constant for heat transfer through 1/4" hot rolled steel (33,475)
Btu/hr = total number of Btu's available in one loading of the fire box divided by an estimated time for the combustion of the wood (7 hrs.)
H_p = a factor for converting the area of absorption to boiler horsepower (10)

so:

$$A = \frac{(10)\ (117,857)}{33,475} = 53.13 \text{ square feet}$$

The original design for the boiler was a simple cylinder inside a larger cylinder. However, it was found that this design did not have enough surface area for heat absorption. As a result, a design was used that incorporated fire tubes that would greatly increase the area for heat transfer. Table 3, p. 9, lists the sizes of areas of the boiler that are subject to heat transfer.

TABLE 3

AREA OF HEAT ABSORPTION IN THE BOILER

Part	Dimensions	Area
Top (fire box)	2' x 4'	8 sq.ft.
Sides (fire box)	(2' x 4')2	16 "
Back (fire box)	2' x 2'	4 "
Fire tubes	(3"dia.,33"long)18	38.88"
TOTAL		66.88

The fire tubes are mounted horizontally above the fire box so that the burning gases pass out the back of the fire box and enter the fire tubes (refer to figure 1, p. 10). The gases then move forward through the fire tubes and up the flue at the front of the boiler. The complete fire box (excluding the door) is jacketed with water and in addition, a water reservoir surrounds the fire tubes. Three one-inch inlets are fitted at the base of the boiler for cool water returning from the heat storage unit and one three-inch outlet at the top of the boiler near the flue for water convecting to the heat storage unit.

Access doors were provided to the ends of the fire tubes due to the fact that they are subject to sooting which reduces the efficiency of heat transfer. It is a simple

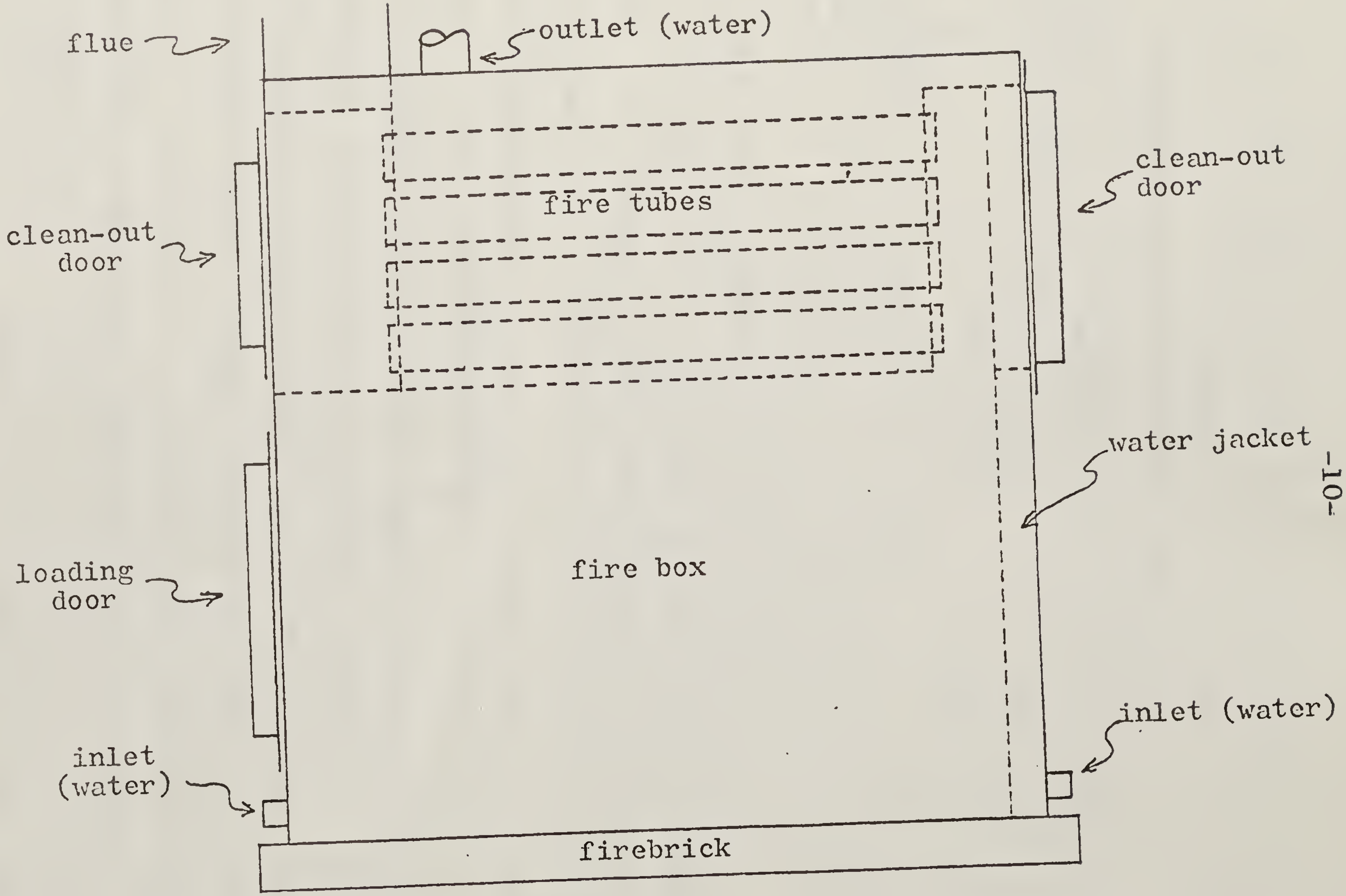

FIGURE 1. Fire tube boiler (side view).

matter to remove one of these doors and run a cleaning rod down the tubes to remove the soot.

When using hot rolled steel that will be exposed to high heat, there is a possibility of warping. To alleviate this problem in the clean-out doors, a lining of 3/8" asbestos sheet, four layers thick, was installed to insulate the sheet metal from the heat. These doors and the fire box door were also reinforced around the periphery with angle iron. This creates a heavy but very stable unit.

HEAT CIRCULATION AND DISTRIBUTION

Basically, there are two circuits in the circulating system. One circuit connects the boiler to the heat storage unit. The other circuit connects the heat storage unit to the radiators that transfer the heat from the water to the air that heats the house (refer to figure 2, p. 12).

The boiler to heat storage unit circuit is simple in design. It consists of one three-inch line that connects the bottom of the heat storage unit to the bottom of the boiler. The other three-inch line connects the top of the boiler to the top of the heat storage unit. Three-inch plumbing was used to allow a large volume to flow and there are no valves or pumps in the circuit. The principle of

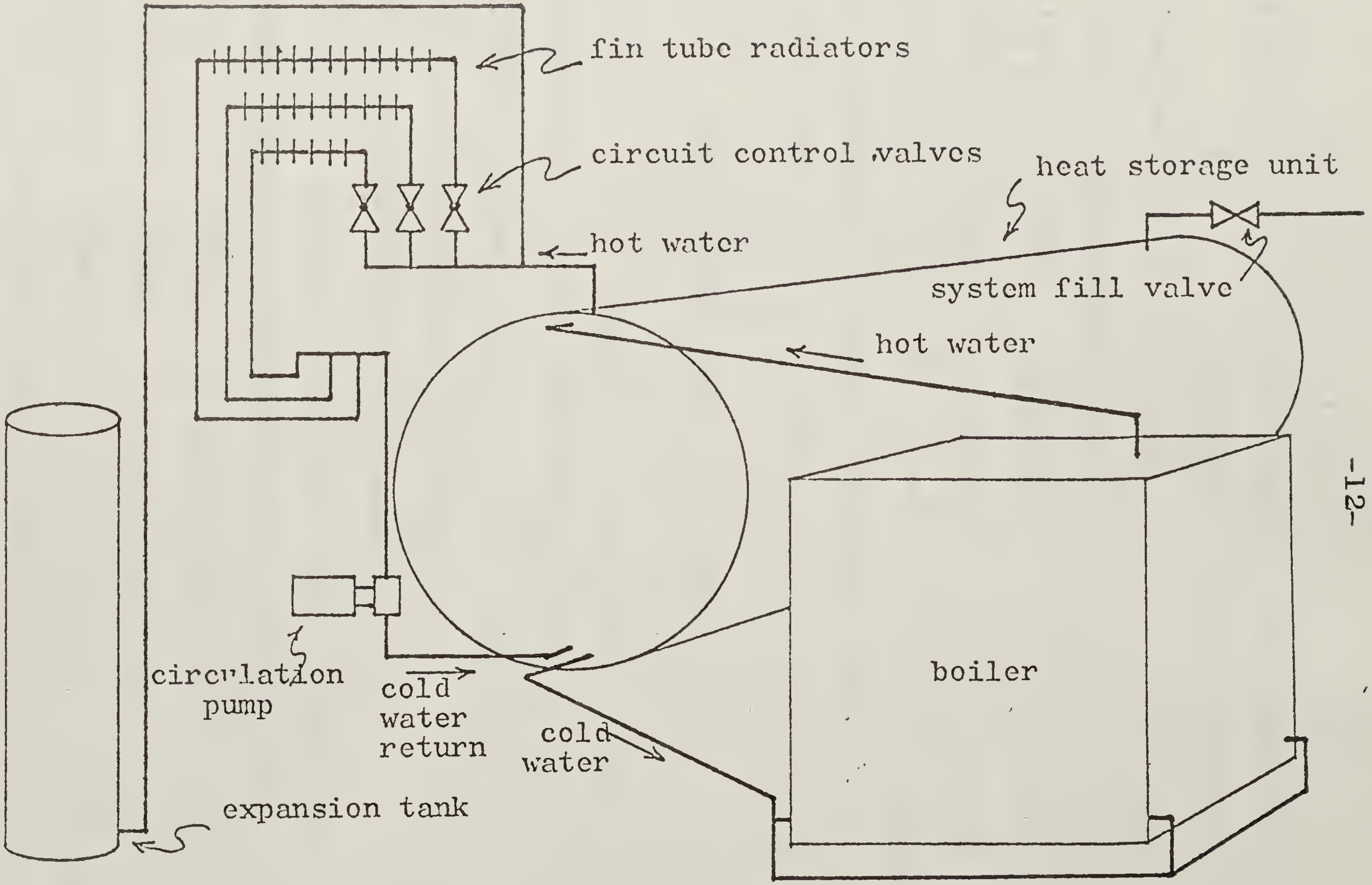

FIGURE 2. Heating system schematic.

convection (hot water, being less dense and lighter, rises) is used to transfer water from the boiler to the heat storage unit. A pump or valve installed in the circuit could cause a constriction in the line through loss of electricity to the pump or inadvertent closing of the valve. This constriction would allow steam to be produced in the boiler and create the possibility of increased pressure which the system could not handle.

The other circuit is used to transfer hot water to the radiators from the heat storage unit. It consists of a large line that is plumbed to the top of the heat storage unit to pick up hot water for the radiator system. This line is divided into separate circuits at a manifold that distributes the hot water to different areas of the house. There are three sub-circuits, one going to the family room and utility room, one going to the living room, and one heating the master bathroom. Each of these circuits is fitted with a valve that adjusts the flow to each circuit. The sub-circuit used to heat the living room also passes through a coil installed in a concrete slab in the floor of the entryway.

The radiators used in these sub-circuits are conventional fin tubes, suspended just under the floor joists.

They are designed to heat the floor of the room above.

The return line from these sub-circuits then connects to another manifold that is connected to the bottom of the heat storage unit.

A hot water circulating pump was fitted between the manifold and the heat storage unit and then wired to a thermostat in the house. As the house cools off, the pump circulates water to the radiators raising the air temperature in the house, and shuts off when the air in the house reaches the pre-set temperature on the thermostat.

The inlet and outlet of heat circulation circuit and boiler circuit are plumbed to the storage tank in such a way that the water in the heat storage tank can be somewhat isolated. This may be desirable if the water in the heat unit is cold and there is a demand for heat in the house. A fire can be built in the boiler and the hot water will pass into the tank and directly into the heat distribution system for quick heat in the house.

The water pressure in the whole system is regulated by three means. First, a pressure reducer valve was fitted which serves to fill the system with water. This valve isolates the domestic water from the water in the heating system and maintains the pressure in the heating system at about six pounds. As the pressure in the heating system drops below this pre-set pressure, the reducer valve allows water to flow from the domestic water supply to the heating system until it returns to pressure.

A second means of limiting the pressure in the heating system is the use of an expansion tank. As the water in the system gets hotter, it expands and the expansion tank provides a place for this extra volume without increasing the pressure above a safe limit. The expansion tank is basically an air cushion in the system; as the water expands, it begins filling the expansion tank thus compressing the air in the tank. The size of the expansion tank was computed by finding the expansion of the volume of water used in the system. With a temperature increase of 150°F (50°F incoming water, to a high of 200°F water temperature in the system after heating), the water was found to expand in volume by 56.96 gallons.* Because the system could not tolerate a substantial increase in pressure, a 160 gallon expansion tank was used. This will increase the pressure in the system 6-8 pounds which is within the pressure limits of the system.

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* Louis Allen Harding and Arthur Cutts Willard, Heating Ventilation and Air Conditioning (London: Chapman and Hall, 1937), p. 20.

If the pressure should increase to a point that threatens the components of the system, a pressure relief valve will open and allow the pressure to drop. This valve is plumbed into the top of the tank and is fitted with a bleed-off line to a drain.

The materials for the boiler and the plumbing were obtained through local steel supply houses and plumbing shops. The basic heat storage unit was fabricated in Billings by Empire Steel and was subsequently modified to fit the needs of the system.

B. System Installation

Fabrication of the boiler was begun in January of 1977 and was completed in April of the same year. Approximately 150 man-hours were required to complete the boiler and these were contributed by Richard Hagan and Don Lee, a local welder.

The heat storage unit was being fabricated during this time and was modified before it was installed in the basement of the house. In the spring of 1977, the boiler and heat storage unit were placed in the basement of the house.

Work began in the fall of 1977 on the installation and plumbing of the system and was completed in March of 1978.

Approximately 150 man-hours were involved in this phase of the installation and these were contributed by Doug Polette and Richard Hagan.

C. System Testing and Modification

PRESENTATION OF DATA

INTRODUCTION

The purpose of evaluating the wood heating system was to determine its efficiency with respect to wood consumption and to compare it to a conventional electrical heating system. In order to perform this evaluation, a number of variables were studied.

First, the amount of heat loss through the building materials for each week was calculated. Then the amount of energy that was used during each week was totaled. From this, the efficiency of the wood heating system could be calculated and a comparison to electrical heating made.

Primary interest was focused on how much heat was realized by the amount of wood or electricity that was used.

BUILDING HEAT LOSS CALCULATION

The process developed by the researcher to find the amount of energy consumed each week was as follows:

> Average temperature difference (inside to outside) per day X building heat loss coefficient per hour X 24 hours X 5 days = Total Heat Loss Per Week

The average temperature difference for each day was found by averaging the temperatures recorded by thermographs at each hour and then subtracting the outside readings from the inside readings. The temperatures were recorded in degrees Celsius and converted to degrees Farenheit, as current methods use the latter for calculation. Table 4, page 20, is a listing of the temperature difference for each day of the week during the study period. This average temperature difference for each hour of the day was then multiplied by the heat loss coefficients for the building systems in the house and then multiplied by 24 to find the heat loss for that day. These heat losses were totaled to find the heat loss for the five days under study. The five day period was used to allow two days between runs for time to switch from one heat source to the other.

It is revealed in Table 4 , page 20, that the weather was reasonably uniform throughout the five week test period. During the weeks in which wood was used as a heat source, the temperatures were slightly lower thus creating a higher heat loss in the house.

These figures show the heat loss from the house only and do not account for heat loss in the basement or through the floor. These additional heat loss figures were added

TABLE 4

DAILY AVERAGE TEMPERATURE DIFFERENCE AND HEAT LOSS IN GROUND FLOOR OF HOUSE.

	Date	Ave. Temp. Diff.(F°)	24 Hr. Heat Loss Btu	Date	Ave. Temp. Diff.(F°)	24 Hr. Heat Loss Btu	Date	Ave. Temp. Diff.(F°)	24 Hr. Heat Loss Btu
Wood	3/20	31.17	260,864.4	4/3	35.55	297.519.36	4/16	29.34	245,549.76
Heat	21	31.52	263,793.6	4	26.45	221,361.12	17	35.05	293,337.36
	22	33.82	283,042.56	5	31.09	260,193.36	18	29.63	247,976.88
	23	34.97	292,667.04	6	35.40	296,263.92	19	24.33	203,620.56
	24	32.96	275,845.2	7	37.70	315,512.88	20	26.03	217,826.4
		TOTAL	1,376,212.8		TOTAL	1,390,850.5		TOTAL	1,208,310.9
Electrical	3/27	28.49	238,434.0	3/10	26.32	220,273.2			
Heat	28	28.06	234,835.2	11	30.67	256,678.56			
	29	25.07	209,811.84	12	35.17	294,339.12			
	30	21.24	177,758.4	13	32.71	273,751.2			
	31	23.59	197,425.44	14	29.47	246,635.52			
		TOTAL	1,058,264.8		TOTAL	1,291,677.6			

to the total for each week as the conditions in the house changed with each shift in the heat source. During the weeks in which electricity was used to heat the house, the basement was not heated and the heat loss through the floor was added to the total loss through the rest of the house. The basement was considered to have a temperature equal to that of the surrounding ground (45°F) and the temperature differential was determined using the heat loss coefficient of the flooring system and a temperature difference of 25°F (70°F - 45°F).

During the weeks in which wood was used as a heat source, the basement was heated along with the house. This was due to the fact that radiators for the hot water system were suspended from the floor joists and there was no insulation under them to isolate the heat and force it to conduct through the floor. As a result, the heat loss through the uninsulated concrete walls was added to the heat loss in the house. This heat loss is considerable in comparison to the total loss from the house, as noted in Table 5, p. 22.

TABLE 5

TOTAL HEAT LOSS PER WEEK, HOUSE AND FLOOR OR BASEMENT

Week	Heat Loss House Btu/wk	Heat Loss Floor or Basement Btu/wk	Total
Mar. 20-24	1,376,212.8	4,821,336.0	6,197,548.8
Mar. 27-31	1,058,264.8	22,412.65	1,080,677.4
Apr. 3-7	1,390,850.6	4,821,336.0	6,212,186.6
Apr. 10-14	1,291,677.6	22,412.65	1,314,090.2
Apr. 16-20	1,208,508.8	4,821,336.0	6,029,644.8

The total heat loss for each week can then be compared with the amount of energy used that week to show the efficiency of heat heating system.

D. System Efficiency

ENERGY USE CALCULATION

The amount of electricity used during each week that the electric baseboard heaters were used to heat the house is a simple calculation. The kilowatt hour meter isolating the electric baseboard heaters was read at the beginning and end of each week. The difference in readings from beginning to end was then multiplied by 3,413* to give the number of Btu's in electrical energy used that week. These totals are shown in Table 6, page 23.

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*Conklin, p. 167.

The amount of energy used during the weeks that the wood-fired boiler was used to heat the house was found by weighing all the wood used that week. Because all wood has 8,600 Btu's per pound (with the exception of highly resinous wood), the total weight of wood consumed could be converted into Btu's used that week. These totals are also presented in Table 6.

TABLE 6

TOTAL HEAT LOSS VERSUS ENERGY USED

		Wood		Electricity	
Week	Total Heat Loss (Btu/wk)	Amt. Used (lbs)	Energy Used (Btu)	Amt. Used (kwh)	Energy Used (Btu)
Mar. 20-24	6,197,548.8	894	7,688,400		
Mar. 27-31	1,080,677.4			228	778,164
Apr. 3-7	6,212,186.6	902	7,757,200		
Apr. 10-14	1,314,090.2			275	938,575
Apr. 16-20	6,029,644.8	976	8,393,600		

During the weeks of March 27-31 and April 10-14 when the electrical system was in use, the amount of electricity needed in Btu's was less than what was actually lost in the house. The electric resistance type heaters used are 100% efficient and no account was made for other sources of heat such as sun infiltration and cooking. The sun infiltration on an uncurtained window can be a significant contributor.*

It should also be noted that the energy-used calculations do include the two days between the testing period while the total heat loss is only calculated on the five day testing period. This occurred because there was considerable overlap on the heating sources due to the fact that it was difficult to start and stop each system abruptly. There was also considerable residual heat left in the house at the end of a test period that would be included in the next test period. However, these figures are used in a comparative sense and should not affect the results because the same method was used for each energy source period.

BOILER EFFICIENCY

The efficiency of the boiler in the number of Btu's that it can extract from the burning wood versus the potential number of Btu's that are available in the wood can be calculated from the data in Table 6, page 23. Table 7, p. 25 presents the appropriate data describing the efficiency of the wood fired boiler.

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*Conklin, p. 34.

TABLE 7

EFFICIENCY IN PERCENT OF THE WOOD-FIRED BOILER

Total Heat Recorded in House (Btu)	Potential Heat of Wood Used (Btu)	% Heat Contributed by Other Sources (Btu)	Total Heat Extracted by Boiler(Btu)	Efficiency of Boiler (%)
18,439,379	23,839,200	28.31	13,219,191.0	55%

Data in Table 7 reveal the total heat recorded in the house is an addition of the heat losses in the house for the three weeks that wood was used as the heat source. The potential number of Btu's available in the wood was found by adding the pounds of wood used for the three weeks and then multiplying by the number of Btu's in a pound of wood.

Because there were other contributors of heat during the test period such as sun infiltration, cooking, and heat from people in the house, only part of the total heat loss recorded in the house was contributed by the wood heating system. Due to the fact that the electrical resistance heater is 100% efficient, the additional amount of Btu's recorded in the house during the test periods which used electricity can be used to find the percentage of heat contributed by other sources of heat. It was found that the electrical heaters accounted for 71.69% of the total heat recorded in the house during the electrical heating test period (1,716,739 divided by 2,394,767.6 multiplied by 100; data from Table 6 ,p. 23); therefore 28.31% was contributed by unrecorded heat sources.

When 28.31% of the heat recorded in the house is subtracted from the total heat recorded, the total heat recorded in the house that was contributed by the wood heating system is found. The efficiency can then be calculated using this adjusted heat recorded datum (13,219,191.0 divided by 23,839,200 multiplied by 100, or 55% boiler efficiency).

WOOD VS. ELECTRICITY: COST ANALYSIS

Using current rates for both electricity and wood, a direct comparison can be made of the energy sources used in this study. This information is summarized in Table 8 page 27.

The amount of wood or electricity used and the corresponding number of Btu's that were actually realized in the heating of the house are taken from Table 6, p. 23. In the case of wood, the three weeks during which wood was used as the heat source were added together. Likewise, the two weeks during which electricity was used as the heat source were added.

TABLE 8

ENERGY SOURCE USE AND WOOD VS. ELECTRIC COST COMPARISON

Energy Source/ Amount Used		Cost of Energy Source		Cost Comparison	
Wood (lbs/Btu)	Electricity (kwh/Btu)	Wood ($/lb.)	Electricity ($/kwh)	Wood ($/mil.Btu)	Electricity ($/1 mil Btu)
$\frac{2772}{18,439,379}$	$\frac{503}{2,394,767.6}$	.0114889	.02803*	1.727	5.89

*On 503 kwh pro-rated

The cost of wood as an energy source in Table 14, p. 51 was calculated by first finding the volume in cubic feet in a cord of wood. Because part of that volume is due to air spaces in the stack, 80% of the total volume was used. Therefore a cord of 128 cubic feet (4' x 4' x 8') is multiplied by 80% to find the actual amount of wood in the cord. This figure (102.4 cubic feet) is then multiplied by 25.5 pounds per cubic foot to give the number of pounds in a cord of lodgepole (2611.2 pounds). At $30.00 per cord of firewood, the cost of a pound of firewood can be found by dividing $30.00 by 2611.2 pounds, resulting in $0.0114889 per pound of lodgepole.

The cost of electricity recorded in Table 8, p. 27 was found by using the total kilowatt hours used during the two week test period and applying this total to the current rate schedule:

TABLE 9

SCHEDULE FOR CALCULATING COST OF ELECTRICITY USED

Kwh	Rate(¢/kwh)	Cost($)
first 20 kwh	.0169	.338
next 80 kwh	.0538	4.304
next 100 kwh	.0376	3.760
any add. 303 kwh	.0188	5.6964
TOTAL 503 kwh		$14.0984

Therefore, for 503 kilowatt hours, 2,394,767.6 Btu's were realized in the house and they cost $14.10. The cost of $0.02803 per kwh reported in the table is a division of 503 kwh by $14.0984 to find the cost per kilowatt hour for this study and is only true if 503 kilowatt hours are used

The cost of each energy source is found by multiplying the cost of each per pound or kilowatt hour by the number of pounds or kilowatt hours used. The result is then divided by the number of million Btu's realized in the house in each case. Thus the cost per million Btu's of wood was found to be $1.73 and the cost per million Btu's of electricity was found to be $5.89.

CONCLUSION

The major purpose of this chapter was to evaluate the performance of the wood-fired boiler in terms of efficiency and to compare it to an electrical heating system. To accomplish this, the amount of heat that was realized in the house was compared to the actual energy input to each heating system. These figures were then translated into cost of each energy source to find whether a wood heating system was competitive with an electrical heating system. The efficiency of the wood-fired boiler was determined by measuring the potential energy input and comparing it to the energy that was transferred to the water for heating the house.

In summary of the data presented in this chapter, the wood heating system provided heat at $1.73 per million Btu's, the electrical heating system provided heat at $5.89 per million Btu's and the boiler operated at an efficiency of 55%. Therefore, a dollar's worth of wood is equal to $3.40's worth of electricity.

E. System Cost

The following table lists the costs of the project. The items with asterisks (*) are costs that were not reimbursed by the grant.

TABLE 10

Item	Cost
Materials:	
tank (fabrication and shipping)	$490.00
boiler	
pipe (fire tubes)	55.00
steel (flan and angle iron)	482.72
fire brick	35.33
misc. (bolts, fittings, door seal, etc.)	17.73
timbers (tank support)	75.00
pressure tank (120 gal.)	166.55
pressure tank (40 gal.)*	80.00
thermographs	359.00
welding rod and gas	42.55
asbestos (door liner)	21.90
plumbing materials	
pipe, pump, threading, fittings, valves, air relief valves, etc.	897.15
insulation	157.90
gas (plumbing)*	7.50
flue tile*	75.00
plumbing supplies	
pressure guage, drain pipe, 2-in. valve, hot water preheat, thermometers, etc.*	657.50
concrete (floor and walls)*	525.00
Labor:	
boiler fabrication	750.00
plumbing and installation	200.00
Travel:	
trip to Lincoln to see Sherman Cook	90.25
Office supplies:	
communication, final report, etc.	150.00
TOTAL	5,336.08

If the labor on the project had been paid at $7.00 per hour, there would be an additional $1225.00 in the cost of the system. As it was, we did not hire plumbers to install the system and little money was paid for the time spent on the fabrication of the boiler and refitting the storage tank. However, for the sake of realism, this figure should be added to the listed costs in the above table:

$$\begin{array}{r} \$5,336.08 \\ +\ 1,225.00 \\ \hline \$6,561.08 \end{array}$$

F. Economic Evaluation

To calculate the amount of electricity used during a year for the electrical heating season, the following formula was used.

$$\text{Kwh} = \frac{\text{HL} \times \text{DD} \times \text{C}}{\text{TD}}$$

HL = heat loss of the building in kw or total heat loss per hour divided by 3413 Btu in one kw.
DD = annual degree days for the area (7930)
TD = temperature difference between the inside and outside design temperature in degrees F. (90)
C = constant (15)

so:

$$\text{kwh} = \frac{\frac{34209.93}{3413} \text{ X } 7930 \text{ X } 15}{90} = 13,247.61 \text{ kwh/yr.}$$

We can then divide 13,247.61 by 503 kwh (the amount used in the study for two weeks); then times $14.10 (which is what 503 kwh cost in June, 1978) to equal $371.35. This should be a rough estimate as to the fuel costs for one year of heating.

It is estimated that it will cost around $50.00 per year to cut wood for the wood-fired boiler, so this figure is deducted from the $371.35 to equal $321.35. Theoretically, we are saving this amount each year using the wood heating system. If we divide this into the initial cost of the system, $6561.08, it should take about 20 years to pay for the system.

III. Conclusions and Recommendations

One of the initial objectives of the project was to burn wood fast and at a high temperature. This would raise the efficiency of the boiler and reduce the amount of smoke produced. In practice, for the initial hour or so of firing, there was considerable smoke produced which lowered the efficiency of the boiler as those gases were still volatile. The temperatures were not high enough in the boiler to burn them. It would have helped to preheat the intake air, provide secondary air for the flue gases, and force draft the boiler. Plans have been made to modify the boiler before the next heating season to eliminate this problem.

During the test period, the basement was not insulated and this caused heat loss through the basement walls. Before the next heating season, these walls will be insulated which will cut the wood consumption considerably.

In other respects, the system performed as expected.

IV. Monitoring

Each year the number of cords of wood used in the system will be recorded to evaluate the performance of the system.

V. Public Availability

The system is available to be reviewed at any time; please call to set up a time.

VI. Program Evaluation

We have had a problem concerning the time lag between requests and receipts. In all other respects, the Department has been very helpful and cooperative. The program is a good one and should be continued. It provided an opportunity for study that otherwise would not have been within the reach of private parties. It is felt that our project has proven some things about heating with wood that can be used by the general public as well as by other researchers.

15 copies of this public document were published at an estimated cost of $3.50 per copy, for a total cost of $52.50, which includes $52.50 for printing and $.00 for distribution.